A FEW INTERESTING PHENOMENA ON THE ERUPTION OF USU

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The eruptions of Japanese volcanoes for the past fifty years have been almost invariably of the Strombolian type. But recently there have been displayed five different types which may be listed as follows: (1) an appearance of a new volcanic island,[1] (2) a new lava dome in the crater of Tarumai, (3) 45 craterlets on the slope of Mount Usu, (4) ejecting lava up in the craters of Asama[2] and Mihara,[3] and (5) lava flows on Sakurajima. Partial descriptions of the Tarumai and Usu have been published by the writer,[4] while an account by Professor B. Koto of the third will appear in the near future.

In the southern part of Hokkaido, in North Japan, three volcanic eruptions took place between 1905 and 1910. Komagatake was in eruption in August, 1905, Tarumai in April, 1909, and Usu in July, 1910. A line connecting these three volcanoes lies in a northeast to southwest direction and represents the northern extremity of the Nasu volcanic chain. The three volcanoes mentioned are about equally distant from each other (48 km.). The explosion of Komagatake was simple and on a small scale, ejecting fragments around the crater and ashes around the foot of the volcano for a few days only, while that of the Tarumai[5] was more

[1] T. Wakimidzut, "Report on the Ephemeral Volcanic Island in the Iwojima Group," *Bulletin of the Imperial Earthquake Investigation Committee*, No. 56 (1907).

[2] F. Omori, *Bulletin of the Imperial Earthquake Investigation Committee*, VI, No. 1 (1912).

[3] Y. Okamura, *Bulletin of the Imperial Geological Survey of Japan*, No. 48 (1914).

[4] *Report of the Imperial Earthquake Investigation Committee*, No. 64 (1909). Official Report of Hokkaido Colonization (1910).

[5] Y. Ōinouye: *Report of the Imperial Earthquake Investigation Committee*, No. 64 (1911); H. Shimotomai, *Zeitschrift der Gesellschaft für Erdkunde zu Berlin*, No. 9 (1912).

severe. The Usu eruption is the latest one among the three, which was quite similar to that on Etna in September, 1911. This volcano is located between the other two, in longitude E. 140° 49′ 30″ and latitude N. 42° 33′, and lies between "Volcano Bay" on the south and Lake Toya (80 m. higher than sea-level) on the north. Usu is a low, conical, active volcano, 736 m. above the sea, and has a crater 2 km. in diameter, within which there are

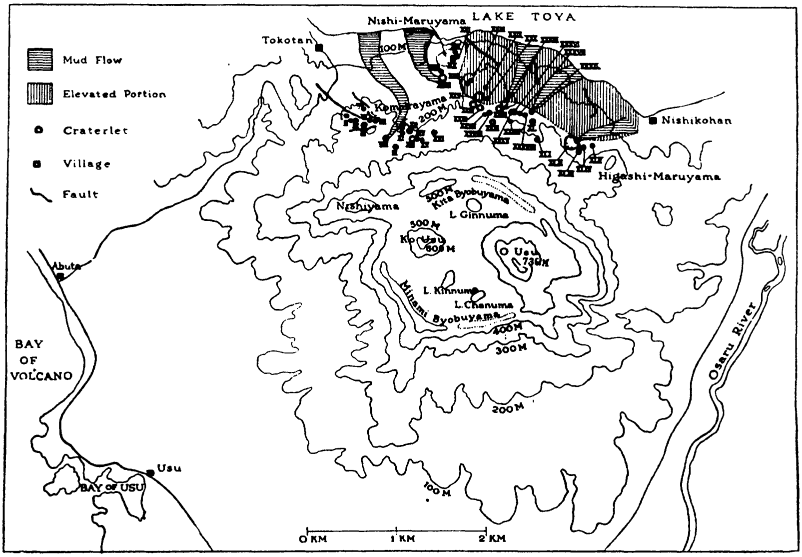


FIG. 1.—Map of Volcano Usu, showing craterlets on the northern slope

two domes occupying respectively the east and the west end of the crater (Fig. 1). The eastern of these domes, O-usu (736 m. AT), looks new, while the western one, Ko-usu (609 m. AT), appears much older. Ko-usu has a few small, steaming pits on the top of its dome, while O-usu has one only on the west side of its dome. The topography, geology, and history of Usu have been well described by Professors F. Omori[1] and D. Sato.[2] Hence only the especially interesting details of the eruptions will be discussed here.

[1] *Bulletin of the Imperial Earthquake Investigation Committee*, V, No. 1 (1911).

[2] *Bulletin of the Imperial Geological Survey of Japan*, XXIII, No. 1 (1913).

I. EARTHQUAKES AND ROARINGS

Preceding the eruption there were frequent earthquakes, seeming to repeat the past history of the mountain, which has always exhibited the "foreshocks" in advance of an eruption. But the writer believes that the occurrence of so many earthquakes in the neighborhood of a volcano within the limits of Japan is a rare phenomenon. It was rumored that slight earth movements were

FIG. 2.—A fissure on the road near Abuta

noticed six days before the eruption. But, as observed by a few persons, the first earthquake began on the evening of July 21, four days in advance of the eruption, and successive earth tremblings were felt from the morning of July 22, continuing through the eruption and for two months thereafter. Numbers of these quakes were felt at Nishimombetsu, 8.4 km. southeast of Usu, 25 on July 22, 110 on July 23, 354 on July 24, 163 on July 25, and thereafter in gradually decreasing numbers. It was on the evening of July 25 that the first eruption took place, and, after it had relieved the strains to some extent, the quakes began to decrease in number.

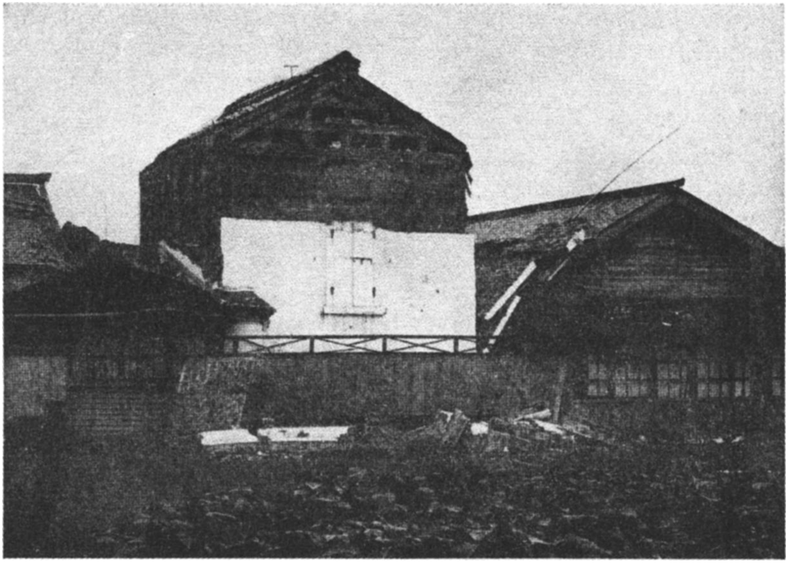


FIG. 3.—A house destroyed by the severe earthquake at 4:30 P.M. on July 24, 1910

FIG. 4.—A monument shaken down by the severe earthquake at 4:30 P.M. on July 24, 1910.

The report of the Municipal Office and the members of the Meteorological Observatory of Sapporo and Hakodate give the numbers in Table I.

TABLE I

NUMBER OF EARTHQUAKES OBSERVED AT NISHIMOMBETSU

Date	Violent	Strong	Weak	Tremor	Total
July 22....	....	....	13	12	25
23....	....	8	48	54	110
24....	1	28	134	150	313+40.5*
25....	1	19	58	85	163
26....	....	1	11	16	28
27....	....	3	14	5	22
28....	....	6	3	8	17
29....	....	1	2	9	12
30....	....	1	3	1	5
31....	....	....	2	1	3
August 1....	....	....	2	4	6
2....	....	....	....	2	2

* Lack of observation for three hours. The number is estimated by means of an average for the three preceding and the three following hours.

From hourly observations the following results were obtained.

From July 22, 7:00 A.M., to July 23, 7:00 P.M., 36 hrs., 66 quakes, 1.8 per hr.
From July 23, 7:00 P.M., to July 25, 8:00 A.M., 37 hrs., 533 quakes, 14.4 per hr.
From July 25, 8:00 A.M., to July 25, 10:00 P.M., 14 hrs., 48 quakes, 3.4 per hr.

The writer's visit to Mount Usu was made on the afternoon of July 24, amid the climax of the quaking. At that time the quakes occurred rather oftener than once in five minutes. The houses trembled so from the subterranean violence that the windows rattled continually throughout the entire day, and made so much noise that no one could stay within the houses. It was noticed that every quake was preceded by the sound which seemed to come from deep within the earth, or as if heavy artillery were being fired in the distance. But sometimes on the east side of the mountain, or in the direction of Volcano Bay, probably owing to the echoes, the same sound was heard. It frequently happened that the sound was first heard in the distance; then a landslide was seen on the dome of O-usu; and following almost immediately the quivering of the earth was felt. A year previous, when the writer visited Usu, a small column of steam was seen to rise from the small pit on the west side of O-usu, and this was the same in

FIG. 5.—The largest mud cone at Usu village. Taken July 30, 1910

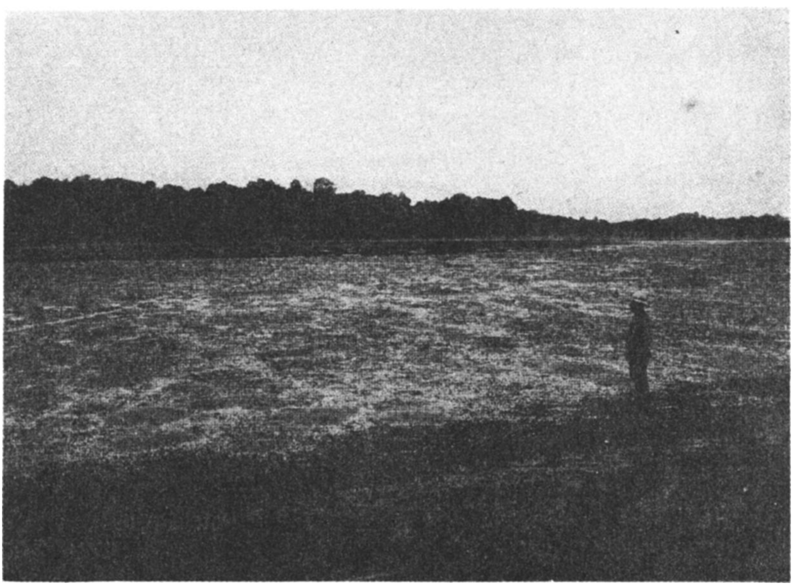


FIG. 6.—Numerous mud cones in the Bay of Usu. Taken July 30, 1910

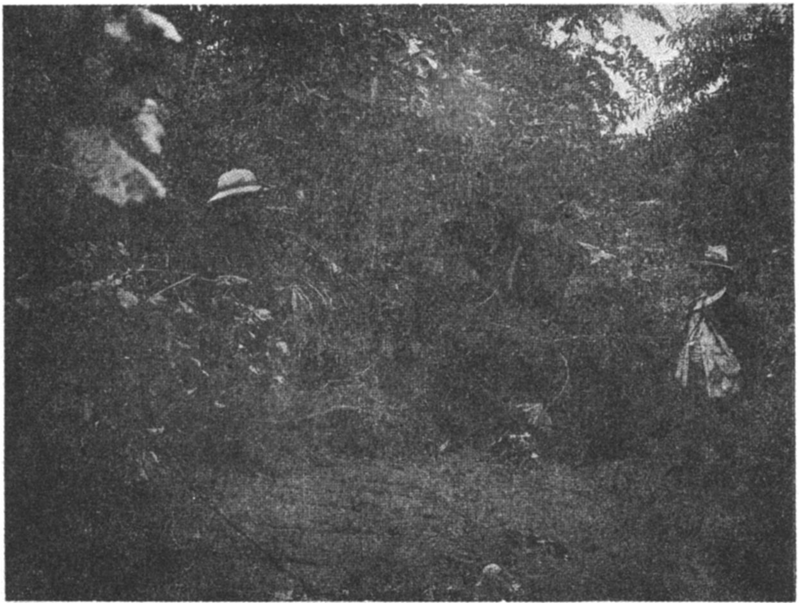


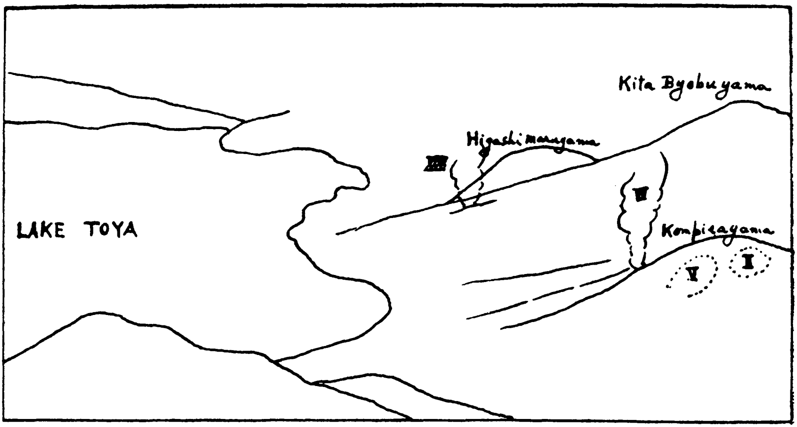
FIG. 7.—A fault of 1 m. throw, at the west foot of the Kompirayama. Taken August 2, 1910.

FIG. 8.—The same fault which has increased its throw to 2 m. Taken September 4, 1910.

amount when the second visit was made during the time of the eruption under discussion. The surrounding country was noted

FIG. 9.—The first explosion crater on the Kompirayama. Taken July 26, 1910

to be the same topographically as it had been on the previous visit. Judging from the history of this volcano, the writer recognized



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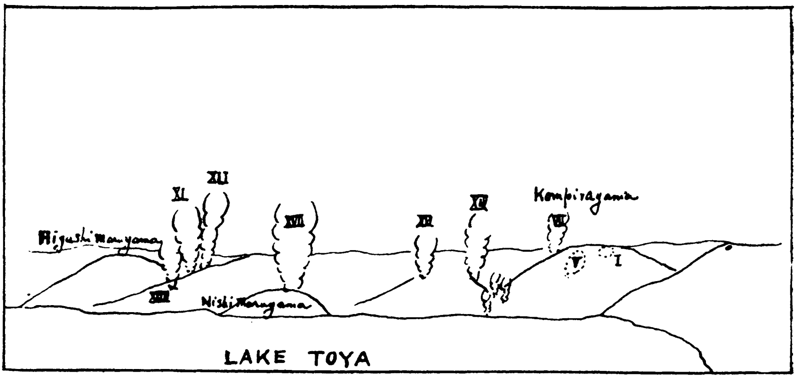

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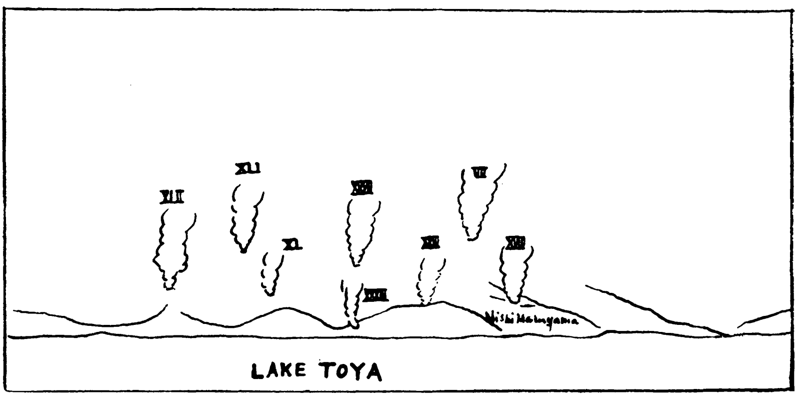

c

FIG. 10*a*.—A sketch of craters from the west. 5:00 P.M., July 27, 1910
FIG. 10*b*.—A sketch of craters from the northwest. 11:20 P.M., July 28, 1910
FIG. 10*c*.—A sketch of craters from the north. 6:00 P.M., July 29, 1910

that the preliminary warnings were the symptoms of an eruption, and, watching the crater every moment during the day and night and the following day, he observed in detail the phenomena. The number of earthquakes, as well as their vigor and intensity, increased. No one could indulge in sound sleep in the neighborhood of the volcano. Cannonading and trembling developed till the introductory explosion took place. Among the several hundred

FIG. 11.—A great column of smoke at the top of Nishimaruyama beyond the steaming mud flow. Taken August 2, 1910.

earthquakes two violent ones are worthy of mention, one at 4:30 P.M. on July 24, and the other at 5:00 P.M. on July 25. Monuments fell, houses were badly damaged, the earth was ruptured, and many mud cones were formed around the volcano (Figs. 2–6). The earthquake wave reached an average radial distance of 65 km. outward from Usu, except in the southwesterly direction, where it reached 140 km. The earth's shaking abruptly decreased after the first explosion, suggesting that strains which had been accumulating were then relieved.

II. EFFECT OF THE EARTHQUAKES

There were several phenomena of interest due to the preliminary earthquakes, such as fissures, faults, and the building of mud cones.

1. *Fissures.*—Many ruptures were made within the circle of severe shaking of the earth, especially on the west side of the

FIG. 12.—South scarp of "graben" at the top of Kompirayama. Taken July 14, 1911.

volcano. The directions of the fissures were almost parallel to the coast line, i.e., northwest to southeast, and their width was from 3 cm. to 40 cm. (Fig. 2). Close to the mountain, on the west side, the direction changed to east-west.

2. *Faults.*—Two distinct faults extending east and west were made on the west foot of the Usu. Stepping down toward the north (downthrow side on the north), the throw of the southern fault measured 30 cm. and that of the northern one 1 m. The former extended about 50 m. and the latter 600 m. in length. On September 2 an additional throw of 1 m. was noticed, developing

numerous small parallel fault fractures besides showing 2 m. of horizontal shifting (Figs. 7 and 8).

3. *Mud cones.*—The mud cones are small mounds of mud and sand, well stratified and laminated. They range in size from several centimeters to three meters in diameter, and are flat and conical in shape, the angle of slope being from 3 to 16 degrees. The smallest cone seen measured 10 cm. in diameter, and the largest

FIG. 13.—North scarp of "graben" at the top of Kompirayama. Taken July 14, 1911.

5 m. (Fig. 5). The height of the former was 3 cm. and that of the latter 60 cm. Great numbers of such cones were formed in the bay at the southwestern foot of the mountain, distributed irregularly upon the tidal flat (Fig. 6). About 200 m. from the shore line there is a row of such cones trending generally northwest-southeast. While this row of cones is roughly parallel to the shore line, and consequently fairly straight, there are numerous bends in the line. From the structure of the cones it follows that there must have been a periodical eruption of the sand and mud. The laminations, ranging from 5 mm. up to 3 or 4 cm., are roughly proportional

to the size of the cone, the thicker laminae being found in the larger cones. As is usual with all the cones of this region, it was cold water that issued from them before the eruption of the volcano.

On the north side of Usu a few cones were found on the flat farm land at the foot of the mountain. At no other place in the neighborhood were these phenomena observed. All the cones were

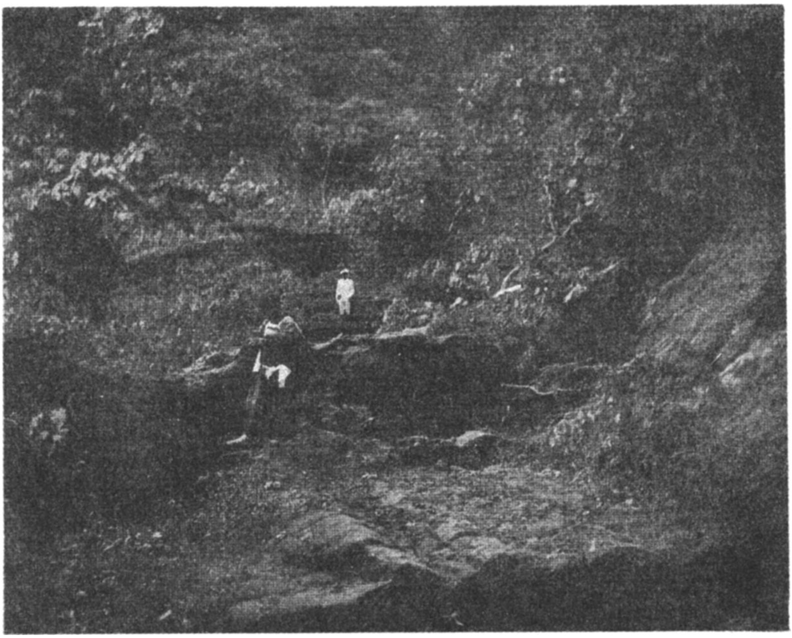

FIG. 14.—Step fault at the west foot of Kompirayama. Taken August 18, 1910

formed by the first severe earthquake, which occurred at 4:30 P.M. on July 24, 1910. The phenomenon is not a peculiar one, for such cones have been reported at many places where strong earthquakes have taken place. They are invariably located along the crack formed by the earthquake where the ground-water issuing through the newly opened vent brings sand and mud with it to the surface. After the eruption of the volcano the mud cones ceased to be active and were gradually obliterated by the process of erosion.

4. *Rise of the water-level in near-by wells.*—Practically all the wells in the neighborhood of the volcano showed a rise in the

water-level; very few showed a decrease. In most cases it was noted that the water in the wells increased to about double the normal volume, while at the same time it became turbid and dirty, owing to the particles of dry mud which fell from the wells into the water below. The rivers of the region also became brown and turbid from slumping of the clay banks. On the southeast side of the mountain several new springs were formed which are still flowing.

III. EXPLOSIONS

After July 22 frequent earthquakes took place, their intensity and numbers increasing hour by hour till 10:00 P.M. on July 25, when the first explosion took place on the northwest side of Kompirayama, a parasitic cone, on the northwest slope of the main volcano (Fig. 9). For a few hours red-hot bombs were ejected on the north side of the cone and made numberless holes in the roofs of the houses in the near vicinity. When the writer visited the region on the following morning, the vent was entirely free from escaping steam, making it possible for him to descend into the crater. At 2:13 P.M. on July 26, a second explosion, preceded by roaring and trembling, took place 200 m. southeast of the first crater accompanying two small explosions. This explosion ejected black and white smoke to a height of about 700 m. That night the smoke stopped for a few hours, but again, beginning at three o'clock in the morning, the roaring became louder and louder as of strong thunder near by, till four o'clock, when it gradually subsided. Meanwhile frequent earthquakes accompanied the formation of three or four explosion craters. In the afternoon of the next day, July 27, the writer saw the ejection of smoke in two craters east of the crater mentioned above (Fig. 10*a*). At 7:00 A.M.

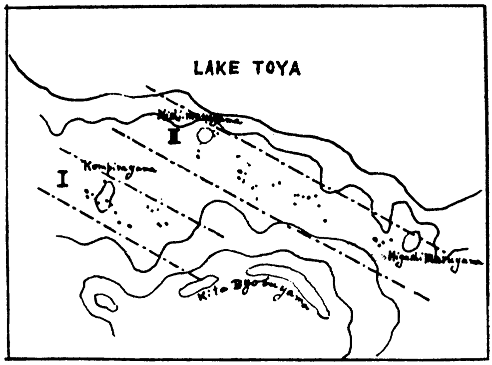

FIG. 15.—Two groups of craterlets. Group I is located at the southwest of Group II.

on July 28, roaring again began, and two explosions took place in sight of the writer at 11:20 A.M. (Fig. 10*b*). The loud roaring continued till eight o'clock in the evening. On the same day there was heavy rain all day accompanied by loud thunder, intense lightning, loud roaring in the ground, and much dense smoke hiding the mountain entirely from view. Before 9:00 A.M. on July 29, judging from the numbers of smoke vents found on that morning, several more explosion craters were formed (Fig. 10*c*).

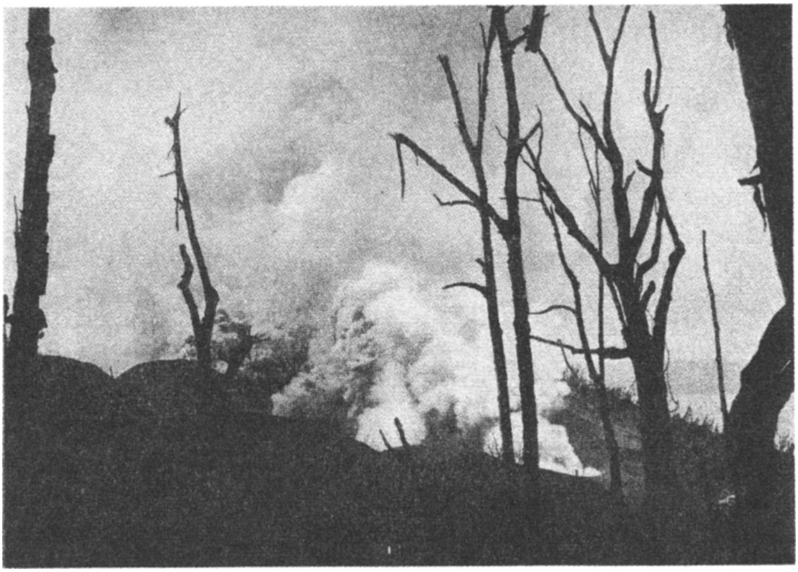

FIG. 16.—A group of craterlets on the second group. Taken September 4, 1910

On August 2 two new craters were formed at the top of Nishi-maruyama, a parasitic cone. For a week these two craters poured forth an astonishing amount of smoke in a large black column such as was not seen from any other cone (Fig. 11). The volume suddenly decreased at the end of one week. Thus in the period of greatest activity, from July 25 till August 2, the number of craters formed amounted to 15. Thereafter, on August 7 and 8, on September 3, and on October 2, small explosions occurred, so that the total number of craters reached 45. Besides these craters numerous crevices and faults developed on the side of the moun-

tain. At the top of the small parasitic cone, Kompirayama, a "graben" was formed about 30 m. in maximum depth, 100 m. wide, and roughly 500 m. in length (Figs. 12, 13). Westward, across the road, the same faulting was found to be "step faulting," with the northern blocks downthrown (Fig. 14). It seems apparent, therefore, that the northern fault of the "graben" is a "scissor fault," reversing its throw on crossing the road. Close to the second group[1] of craterlets, at the same time, were formed many

FIG. 17.—Mud-flow from crater No. VII. Taken August 2, 1910

faults, among which were some forming fault scarps of 5–7 m. in height. The trend of both systems of faults is west-northwest by east-southeast. It is noteworthy that such a large number of craterlets formed in the ten weeks of the eruption.

1. *Process of explosion.*—The order of formation of these craterlets was as follows: In the beginning a cannon-like sound was heard, the ground cracked open in a straight line in the form of a V-shaped crack (Fig. 9), and white smoke issued from the vent. Then followed black smoke together with sand and ashes.

[1] See Fig. 15.

This is the normal order of eruptions for all the craters. The ashes and bombs ejected from the fissures upon the sides of the crevice, after a day, or at most a few weeks, built up a cone. The rapidity with which the cones were built depended on the size of the orifice and the amount of ejectamenta. The angle of slope of the cones ranged from 15 to 30 degrees, the steeper ones being made of the rather coarse material. As the cones grew, the old vents became quiescent and new ones broke out on the side of the

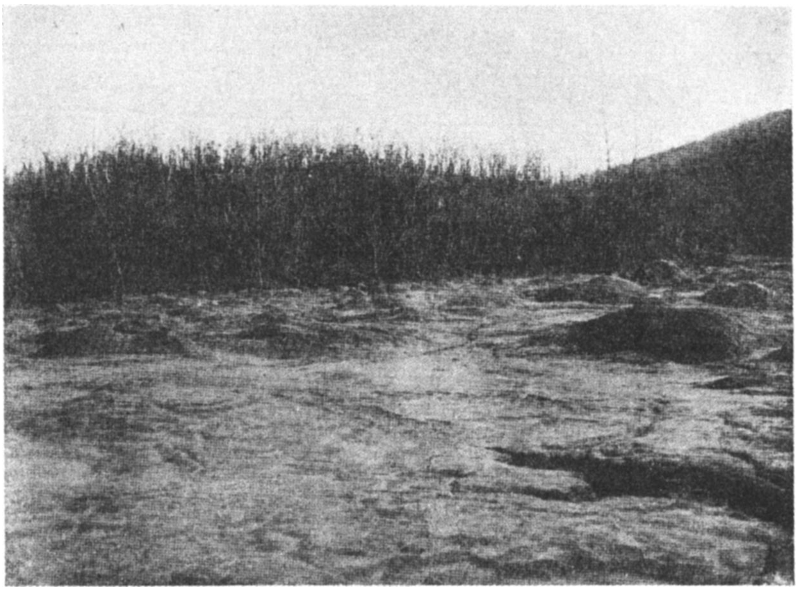

FIG. 18.—"Puff cones" on the mud-flow. Taken August 19, 1911

cone, and the ejectamenta, filling the old crater, sometimes obliterated it.

The life-history of the different cones was not the same, some of them becoming quiescent after only one explosion, others continuing for several days to roar and emit black smoke and to build cones. Some of them emitted smoke intermittently, being active for a few days and then quiet for a few days and then active again, etc. Besides the smoke, ashes, sand, and bombs, a large amount of mud[1] flowed from five of the craters.

[1] *Jour. Geol.*, XXIV, No. 6.

2. *Explosion craters.*—The 45 craters are arranged in two groups (Fig. 15). The first, consisting of 16 craters lying north-northwest of Mount Usu, is aligned in a west-northwest to east-southeast direction. The second group, lying 800 m. northeast of the former, is composed of 29 cones lying in a line parallel to the first group (Fig. 16). The altitude, date of formation, size, shape, and the life-history etc., of each cone in the two groups are tabulated in Table II.

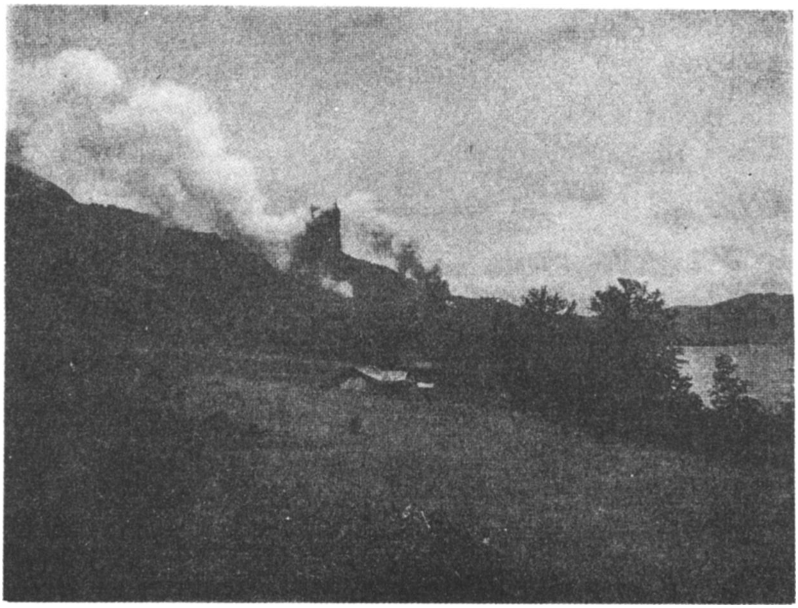

FIG. 19.—Ejection of smoke from crater No. XLII. Taken August 3, 1910

The formation of the cones apparently has no order, though a few in the first of the groups described above formed in sequence, starting from the northwestern end and proceeding toward the east. But in general the action was begun in the first group and finished in the second group.

3. *Ejectamenta.*—Ash, sand, and bombs, with SO_2 and H_2S, were ejected in the black smoke and carried to the lee by the wind, some of the ashes quite a distance. From the first explosion ashes were carried 44 km. toward the northwest of the Usu. Later, ashes from a later eruption were carried 4 km. toward the east and 20 km.

TABLE II

No.	Date	Time	Order	Altitude	Crater			Cone		Remarks
					Shape	Diameter	Depth	Height	Slope	
				m		m	m	m		
I	Aug. 8	2:30 P.M.	13	225	Round	15	5	15	30°	
II	Aug. 8	?	13	245	Round	15	7	7	30	
III	Aug. 8	?	13	250	Round	31	15	0	0	Steaming until May, 1911
IV	July 26	2:13 P.M.	2	270	Ellipse	36×30	13	0	0	
V	July 25	10:00 P.M.	1	240	Ellipse	91×13	18	0	0	Issues smoke and ejects ashes and bombs for a few hours
VI	July 26	2:13 P.M.	2	275	Round	24	9	0	0	Smoke high up to 1,000 m.
VII	July 26	2:13 P.M.	2	275	Ellipse	42×33	10	0	0	
VIII	July 28	......	5	205	Round	22	2	7	30	Mud-flows
IX	......	......	......	220	Ellipse	36×22	13	0	0	
X	......	......	......	220	Round	10	7	0	0	
XI	......	......	......	220	Round	18	9	0	0	
XII	......	......	......	190	Round	15	15	0	0	
XIII	July 29	8:00 A.M.	9	240	Round	91	35	0	0	Emits black smoke daily until beginning of August
XIV	......	......	......	255	Round	45	16	0	0	
XV	......	......	......	255	Round	16	5	0	0	
XVI	July 27	3:00 A.M.	4	250	Round	27	9	4	20	Crater opens toward west
XVII	Aug. 8	Morning	12	160	Round	36	14	9	26	
XVIII	July 28	5:30 P.M.	7	160	Round	100	18	0	0	Crater opens toward west and mud-flows in great quantity
XIX	Aug. 2	3:00 A.M.	11	160	Round	18	7	0	0	Big black smoke for a week
XX	Aug. 2	3:00 A.M.	11	160	Round	23	9	0	0	Big black smoke for a week
XXI	Aug. 2	3:00 A.M.	11	160	Ellipse	40×18	16	0	0	Big black smoke for a week
XXII	......	......	......	210	Ellipse	69×18	32	0	0	Still steaming
XXIII	July 29	5:00 A.M.	8	210	Ellipse	82×42	16	0	0	
XXIV	......	......	......	240	Round	93	40	9	20	Most active in the beginning of September
XXV	Oct. 2	......	14	220	Round	130	80	0	0	The second largest crater and the most active
XXVI	July 29	5:00 A.M.	8	250	Round	84	38	18	32	Most active in the beginning of September
XXVII	July 28	5:30 P.M.	7	250	Ellipse	50×47	24	18	25	
XXVIII	......	......	......	240	Ellipse	50×36	11	20	24	
XXIX	......	......	......	230	Ellipse	27×15,	7	0	0	
XXX	......	......	......	220	Round	90	18	5	20	
XXXI	......	......	......	250	Round	51	29	31	30	Much ejectamenta, and completes the cone on August 13
XXXII	......	......	......	210	Round	76	40	15	20	Steaming on the north wall in the crater
XXXIII	July 26	11:30 P.M.	3	205	Round	64	30	18	18	Mud-flows on July 29, and still steaming
XXXIV	......	......	......	200	Round	31	9	18	28	
XXXV	......	......	......	200	Ellipse	70×20	18	10	20	
XXXVI	......	......	......	200	Ellipse	85×70	37	0	0	More active than XXXV and XXXVII, and overlaps them by ejectamenta
XXXVII	......	......	......	190	Ellipse	54×22	11	0	0	
XXXVIII	......	......	......	190	Round	69	37	23	32	
XXXIX	July 27	3:00 A.M.	4	165	Ellipse	62×40	6	15	25	Mud-flows and partly overlapped by ejectamenta of XXXVIII
XL	July 28	11:20 A.M.	6	175	Ellipse	69×40	10	0	0	
XLI	July 28	11:20 A.M.	6	220	Ellipse	70×60	30	10	20	Crater opens toward east
XLII	July 29	9:00 A.M.	10	220	Ellipse	210×150	90	50	30	Three craters unite and make the largest pit, mud-flows and the most active
XLIII	July 29	9:00 A.M.	10	170	Ellipse	70×24	11	0	0	Crater opens south
XLIV	July 29	9:00 A.M.	10	160	Round	22	7	0	0	
XLV	......	......	......	155	Ellipse	20×10	9	0	0	

toward the south, the amount being greatest on the northwest side of the mountain. In the Kompirayama region the ashes that fell formed a layer up to 8 and 10 cm. in thickness, while at the distance of 1 km. from the mountain thicknesses of 3 mm. to 1 cm. were found. On the north side of the second group of cones, a general thickness of 1 cm. was found, while at their very foot the layer was 30 cm. in thickness. But on the east side and south side of the mountain

FIG. 20.—Bombs and mud-flow from crater No. XLII. Taken July 31, 1910

very little ash was found. Besides the ash, sand, and bombs, from five of the craters mud and hot water were ejected. Among these five craters No. VIII was the first to erupt (Fig. 17), while No. XIII ejected the largest quantity of mud (Fig. 11). From the craters to the lake is an expanse of mud which flowed out to a width of 200 m., a length of 500 m., and a thickness of 1.5 m. In addition to this great quantity of mud on the land there was a large amount that flowed into the lake. The mud is composed of fine, gray-colored plagioclase, hypersthene, augite, and magnetite, with a

small amount of hematite, together with glass in an amount comparable with that of the feldspar. Cone No. XVIII ejected the mud periodically in a geyser-like fashion. The mud contained a large amount of gas which came to the surface of the mud-flow after it had almost solidified, making "puff cones"[1] in great numbers (Fig. 18).

The materials of the mud-flows, the sand of the seashore, and the substance in the mud cones mentioned above, when compared

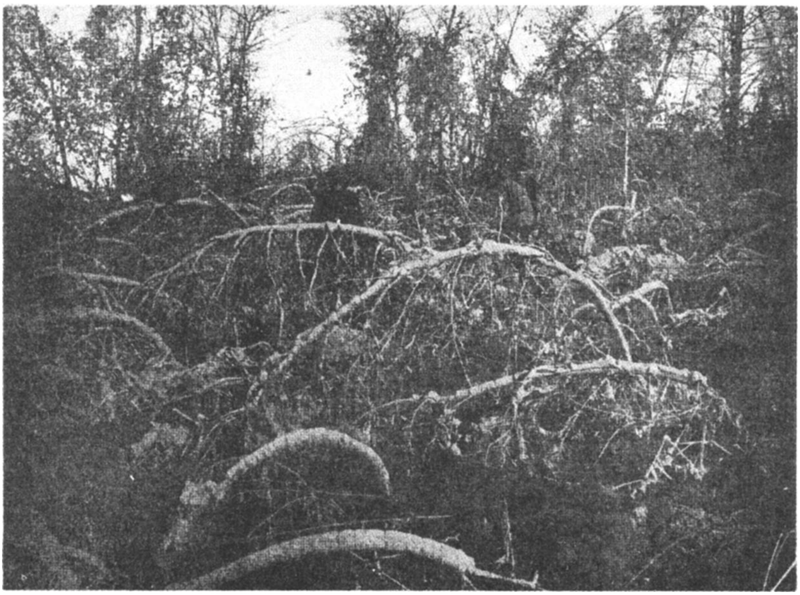

FIG. 21.—Heavily burdened trees near the craters. Taken October 16, 1910

under the microscope, were found to be identical in composition. The fineness, however, is variable; the size of grains in the beach sand being the largest, that in the mud cones intermediate, and that in the mud-flow the finest. The base of the volcano Usu is composed of brown pumice, uniform in constitution throughout the whole region, and the fact that the mud-flows, the cones, and the sand of the beach are alike in composition suggests that they all came from some common source, which in all probability lies horizontally and extends not much below the level of the sea.

[1] *Jour. Geol.*, XXIV, No. 6.

From craters Nos. XXV and XLII great quantities of bombs and sand were intermittently ejected to a height of 700 m. (Figs. 19, 20). The ejected bombs and ashes frequently took the shape of serrate peaks and pinnacles which rose alternately to great heights and then sank back as another one shot up. It was noticed that descending bombs, when struck by rising ones, produced loud reports like the explosion of firecrackers. White, comet-like tails followed the bombs into the air. The largest bomb measured

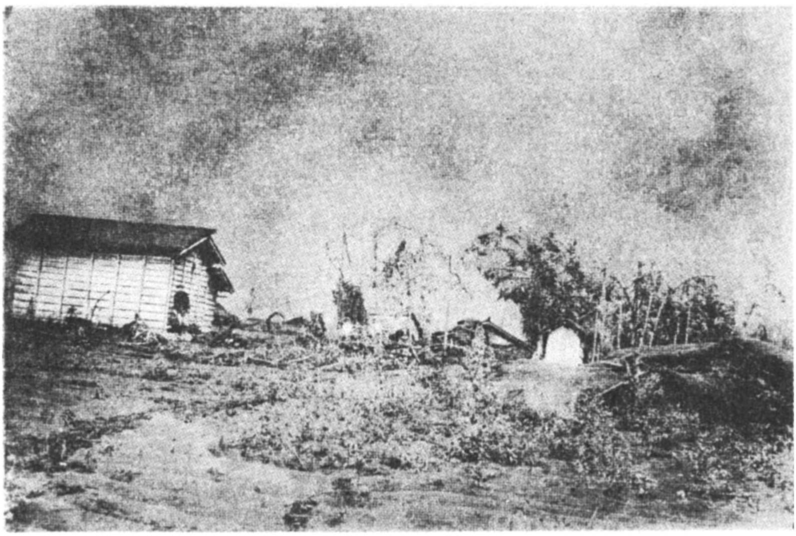

FIG. 22.—Houses inclined 12° owing to the elevation of the left-hand side. Notice a man standing straight. Taken September 4, 1910.

was 25 cm. in diameter and was of the characteristic irregular and rounded shape. The largest hole noted, formed by a falling bomb, was 3 m. in diameter by 2 m. in depth.

Petrography of the bombs (*augite-hypersthene-andesite*).—The bombs ejected from the several craterlets are quite similar, though the percentages of the constituent minerals are slightly different. A brief description follows:

Megascopically, the bombs are dark gray, porous, roundish in shape, and less than 25 cm. across. The pores are very abundant at the surface, slightly less numerous within, and range in diameter

from 1 mm. to 2 cm. The majority of the pores are filled with ashes and sand. Phenocrysts of white plagioclase, which do not exceed 3 mm. in size, produce a porphyritic texture. There are also crystals of dark-colored pyroxene, but they are small and not abundant.

Microscopically, the rock has a hyalopilitic-porphyritic texture. The groundmass consists of dark-brown glass with minute crystals

FIG. 23.—New elevated mountain seen from the east. Taken December 23, 1910

of plagioclase, augite, and hypersthene, and the phenocrysts of colorless plagioclase and green pyroxenes.

Plagioclase is the chief constituent. It is either tabular or equidimensional, and polysynthetic twins and zonal structures are remarkably well developed. Zonally or irregularly included in some of the crystals are patches of brown glass and minute grains of pyroxene.

The extinction angle on the *M* face of the plagioclase is between $-28°$ and $-30°$, and the maximum extinction angle in the symmetrical zone is $+32°$, showing it to be labradorite.

The hypersthene has a slender prismatic habit and strong pleochroism, green to reddish brown.

Augite is usually small in size, mostly in the groundmass.

The rock may be formulated as follows:

$$\frac{P_{40}}{G_{60}}=\frac{\text{Lab.}_{28}+\text{Hyp.}_{8}+\text{Aug.}_{4}}{\text{Glass}_{36}+\text{Lab.}_{18}+\text{Hyp.}_{3}+\text{Aug.}_{3}}$$

P_{40}, 40 per cent of phenocryst.

G_{60}, 60 per cent of groundmass.

Lab., labradorite.

Hyp., hypersthene.

Aug., augite.

Chemical composition.—The rock is rather basic, low in SiO_2, high in Al_2O_3, CaO, and iron, so that some might call it basalt. The writer found a great similarity in mineralogical and chemical composition between the bomb and the lava which forms the old crater ring of the main volcano, as shown by Table III, which gives an analysis of the bombs, with other similar rocks for reference.

TABLE III

	I	II	III	IV	V	VI	VII	VIII
SiO_2	52.40	51.86	51.88	51.32	50.16	52.02	52.86	51.12
Al_2O_3	17.59	21.69	21.53	17.84	17.97	17.14	18.25	19.59
Fe_2O_3	3.51	4.46	2.45	4.34	2.23	7.96	6.61	2.86
FeO	7.07	5.39	6.36	6.70	6.25	3.52	3.39	6.53
MgO	3.73	2.87	2.08	4.18	4.70	3.13	4.27	4.47
MnO	0.16	0.29	0.20	......	0.30	tr.	0.16	0.65
CaO	9.36	10.37	11.09	9.51	11.85	11.57	9.58	9.54
K_2O	1.77	1.08	1.56	1.52	2.80	0.60	0.69	0.57
Na_2O	2.93	2.02	3.12	3.01	3.50	2.38	3.24	3.11
H_2O	0.57	0.26	0.17	1.98	......	0.28	0.69	0.11
TiO_2	1.06	......	......	......	......	......	......	0.86
P_2O_5	0.14	......	......	......	......	......	......	0.14

I. A bomb from Usu, analyzed by *Bulletin of the Imperial Geological Survey of Japan*, XXIII, No. 1.
II. Mean value of three bombs, analyzed in the laboratory of geology in the Agricultural College, Sapporo.
III. Lava of old crater ring on Mount Usu, analyzed in the same laboratory.
IV. Luciite, Luciberg, Odenwald Hesse.
V. Augite-andesite, Kilauea, Hawaii.
VI. Basalt? Yate Volcano, Patagonia.
VII. Pyroxene-andesite, Choa-shen, Kamchatka.
VIII. Basalt, Goentoer lava, Java.
III to VIII taken from J. P. Iddings, *Igneous Rocks.*

IV. DAMAGE

By the fracturing of the earth and the explosions, the deep, beautiful forest on the slopes of the mountain was destroyed. The leaves were all stripped from the trees, the greater number of

which were broken and shattered. Many were blown out of the ground by the explosion, while others were buried and broken by the fall of bombs and ashes (Fig. 21). The bombs, however, were not thrown more than 500 m. from the craters, but the sand and ashes were driven to a distance of several kilometers. Often heavy showers of sand and ashes were seen to fall in localized areas, in many places forming long strips of débris on the land. At one place in a field of barley the strip measured 3 m. wide and was traced for a distance of 200 m. While in the air these masses of ejectamenta looked like a jet of water issuing from a hose. This effect was produced by air currents concentrating the material into long lines. The damage done by falling ash, including injury to farm land as well as destruction of houses, etc., was heavy within a radius of 2 km. of the craters. The most severe damage by ash and mud-flow amounted to 3 sq. km. of land covered. Five houses were carried down to the lake by the mud-flow, and a few houses were buried by the heavy ashes, while five other houses were shattered as a result of the local undulation of the land. At Abuta, a distance of 4 km. from the nearest crater toward the northwest, a monument and a small house fell, together with three brick walls (Figs. 1, 3, 4) and two plaster ones of a storehouse. In the same village many cracks developed in the walls of the houses.

V. CHANGE OF TOPOGRAPHY

On July 28 the writer found the rise of the water of Lake Toya on the north side to be about 30 cm. On August 6 Dr. Omori found a lowering of the water-level on the south side of the lake. From August 20 it was noticed that the north side of the second group of craters began to rise. This elevation (155 m. high from the lake-level, according to Professor F. Omori) continued till the end of November. The slope of the southern shore of the lake was about 5 degrees. It then gradually rose to a slope of 30 degrees at the top of the elevation, and 22 degrees on its flank. A photograph taken by the writer on September 4 shows a house which, originally constructed upright, was then inclined 12 degrees from the vertical. Two days later this house had collapsed (Fig. 22). Before the

eruption the cone Nishimaruyama could be seen from the village of Nishikohan, but as a result of the elevation which took place the view was obstructed. The area of elevated land is about 2 km. in length by 1 km. in width to the edge of the lake, and, judging from soundings made, it extends another kilometer under the water (Fig. 23). The maximum height of the elevation measured about 120 m. (Figs. 24, 25, 26).[1]

FIG. 24. Mountain slope in the beginning of eruption. Taken July 29, 1910

Mr. Ito, of the Sapporo Meteorological Observatory, found a lowering of 36 m. on the top of the new mountain in April, 1911, while Mr. Iizuka, of the Imperial Geological Survey, recorded 43 m. lowering in July, 1911, by an aneroid barometer.

When the gases involved in the lava are expelled in a great quantity, a decrease of volume will take place, and the lowering of the mountain should result from this shrinkage.

[1] This measurement was made by comparing graphically and to scale the photograph taken before the elevation with that taken afterward. This checked well with the reading of the aneroid barometer which nearly coincides with the map of the Imperial Geological Survey of Japan.

Furthermore, there is a remarkable change of height in Usu proper, as is shown by the map of the Imperial Geological Survey, July, 1911. In the topographical map published by Hokkaidocho, the height of O-usu is recorded as 595 m. and that of Ko-usu as 580 m., while the Imperial Geological Survey reports 736 m. and 609 m. respectively. This difference is too great to be regarded as an error in surveying and must mean that some igneous intrusion produced the irregular change of elevation. The writer presumes that the present height of Usu would be found to differ materially from that recorded by the Imperial Geological Survey.

One year after the eruption Dr. Omori[1] observed that there were local elevations and depressions of the ground in the vicinity of the mountain and over an area of 150 sq. km. The Military Survey Department undertook the determination of height at the request of Dr. Omori and found that Mount Usu was raised, while the western foot was depressed. In the following year the same surveyor recorded contrary results; that is, the previously elevated portion had been depressed, while the depressed part was uplifted.

VI. SUMMARY

1. *Earthquakes and roaring before an eruption.*—As a rule the eruption of Usu is preceded by the foreshocks. This, in the opinion of the writer, suggests that the lava reservoir was located nearly at the same depth in the case of the recent eruptions. The magma in the reservoir, becoming highly heated, could not retain the involved gases, and so the maximum strain under the crust was produced by the continuous heating process. The explosion took place when the interior and exterior pressures were not counterbalanced. Thus the pressure of the highly heated magma overbalanced both the atmospheric and the crustal pressures. The ground beneath the surface burst, owing to the intense strain, and produced the loud sound. The speed of the earthquake waves is greater than that of the sound traveling in the ground and the air. The minute tremor which normally precedes the sound was not noticed because there was no seismograph at hand. Hence,

[1] *Bulletin of the Imperial Earthquake Investigation Committee*, V, No. 3 (1913).

in a seemingly contradictory fashion, the large tremor of the earthquake was felt after the sound was heard.

2. *Least resistance.*—From the structural point of view the greatest number of fractures were observed along the sides of the great depression, or along the anticlinal top; and especially large fractures were found close to the edge of the depression. On the coast line of the Pacific Ocean the presence of several volcanic

FIG. 25.—"New Mountain" almost completed. Taken October 25, 1910

zones naturally demonstrates the existence of fractures made by the depression of the Pacific basin. Two recent faults in the vicinity of Usu were made by the earthquakes, many fractures usually accompanying the fissures along the aperture. Coming back to the original Lake Toya, the writer believes that the depression of the ground produced the lake, which is surrounded by comparatively sharp cliffs; as T. Kato stated in his report,[1] there must have been some fractures along the margin of the lake through which Mount Usu erupted. Such fissures, the writer dares to say,

[1] *Report of the Imperial Earthquake Investigation Committee*, No. 62.

are the weak lines around the foot of Mount Usu. The gases involved within the magma found an exit through the old fissures, the lines of the least resistance, which existed under the lava-flow, and thus the two fissure zones, parallel to the shore line of the lake, were made. As in the case of a viscous substance which is being boiled and shows the evolution of gases in certain restricted points which migrate around over the surface of the liquid, we may assume that the gases evolving from the magma are generated at different

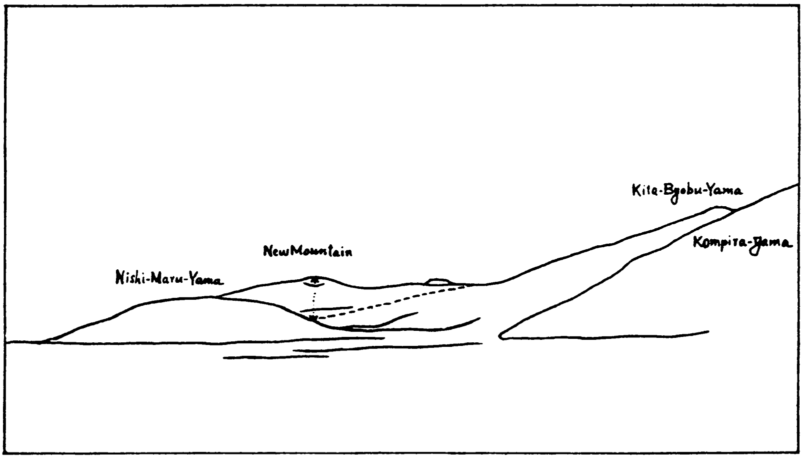

FIG. 26.—Topographical comparison of the north side of the Usu. Broken line, the slope before the elevation. Taken July 29, 1910. Full line, the present relief. Taken October 25, 1910. Dotted line, the actual difference of altitude.

places without reference in time to each other. The irregular eruption of the craterlets may be explained on this hypothesis.

The independent activity of the new craterlets to the old, small, steaming pits on the O-usu and Ko-usu suggests by their lack of sympathy that they do not rise to the surface through the same lava vents and that the reservoirs are not connected.

3. *Origin of the "New Mountain."*—Professor F. Omori[1] stated that the "New Mountain" is due to the intrusion of lava in the form of a spine or dome, and Professor D. Sato[2] believes the intru-

[1] *Bulletin of the Imperial Earthquake Investigation Committee*, V, No. 1, p. 1.

[2] *Bulletin of the Imperial Geological Survey of Japan*, XXIII, No. 1 (1913).

sion to be a laccolith. Many geologists agree with the theory of G. K. Gilbert as to the formation of the laccolith. It is a plausible supposition that the propelling magma would find the line of least resistance in certain planes, lifting the land above it. In the early stages of the activity in Mount Usu enormous quantities of gases were emitted, together with ashes and bombs, while at the mature stage the north side of the second zone of craters was sharply elevated in a straight line. Ernest Howe[1] made experiments on the intrusion of wax into plaster, marble, sand, and coal layers, and demonstrated how the laccoliths are formed. Where there are fissures from the inner source to the surface, there must be a line of least resistance at this place. Intrusion between the strata occurs only where there are no fissures or cracks extending to the surface. It is unreasonable to believe in the intrusion of the laccolith while the distinct cracks shown in the two zones of craterlets are in evidence, as we have seen in the experimental data of Howe. The majority of nearly 150 laccoliths in the western part of the United States of America are composed rather of acidic rocks, while rock[2] as basic as that of Usu is found only in rare cases. The basic lavas preserve a comparatively high degree of liquidity down to rather low temperatures, with a quick process of solidification by rapid crystallization, as is well illustrated in blast-furnace slag. Ejection of many bombs demonstrated that the lava was not seated in the great depths.

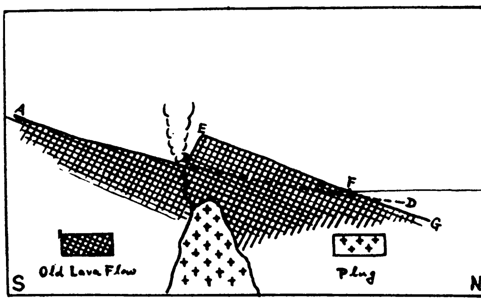

FIG. 27.—A diagram showing the intrusion of "plug": *A*, *B*, *C*, *D*, mountain slope before the eruption; *B*, *E*, *F*, elevated mountain; *C*, shore line before the eruption; *F*, present shore line.

From the facts stated above, the writer is inclined to believe that the formation of a "plug," elongated west-northwest by east-

[1] *Twenty-first Ann. Rept.*, *U.S.G.S.*, Part III (1901).

[2] See the analysis of bomb.

southeast and elliptical in plan, took place in the midst of the activity. Of course, we must not forget that the elevation is not entirely due to the intrusion of the plug, but that there was cooperation of the faulting such as is so remarkably shown on the top of Kompirayama. The elevation of the lake shore on the south side of Lake Toya may be accounted for by the tilting of the crust owing to the intrusion of the plug rather than, as previously supposed, to the formation of a laccolith (Fig. 27). From dynamic considerations it is evident that if the force of the plug intrusion be applied to one end of a resistant section of the earth's crust the whole block will be lifted and tilted.

How could such a very steep slope (40°–70°) on the south side and 22°–30° on the north side be made on the surface by the intrusion of a laccolith? If we suppose that there is a very sharp, steep dome in the great depth overlaid by heavy layers above, its inclination becomes gradually gentle toward the surface, unless the crust be in the liquid or semiliquid condition.

4. *Undulation of ground near Usu.*—From the damage done, and from faults, fissures, and mud cones which were found exclusively on the same side, we may prove that the structure of the western region was originally weak, so that the shaking was intense, while in other parts the effects were comparatively small. Frequent explosion also weakened the already feeble lines.

We may then conclude, from evidence gathered in the field, that there must have been intruded irregular bodies of lava that produced the undulation of the ground near Usu recently observed in the eruption.